# Integrating Nano-Biotechnology and Biotechnology: Advancements and Applications in Biomedical and Health

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## Abstract

Nano-biotechnology comprises the grouping of nano-based materials with biotechnological applications to one of the major fields that has been widely revolutionized in this universe. Nano-biotechnology encompasses nano-based materials which are primarily based on the use of nano-diamonds, carbon nanofibers, quantum dots, carbon nanotubes, and bucky-balls which are majorly used in the field of medicine to support early detection of disease, to treat diseases in a specific or targeted location, tissue regeneration and in biomedical imaging. Current researchers also indicated that the amalgamation of biotechnology and nanotechnology has aided the expansion of point-specific diagnostics and tailored health-detecting structures. In the agricultural, environmental and food industries, the use of nano-based bio-sensors have highly signified the technological ground because of their sensing effects. The functional effect of such nano-scaled materials is very accommodating in giving the exterior surface characters to nanomaterials for increasing the presentation and firmness in numerous areas. Nanotechnology is majorly concerned with ethical dilemmas which usually need to be addressed. This chapter highlights the incorporation of nanotechnology and biotechnology with innovations in the health industry and impacts of nanomaterials while treating health crises.

Keywords: Nano-biotechnology, Nano-diamonds, Carbon nano fibers, Quantum dots, Carbon nanotubes and Bucky-balls

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## Introduction

The reality of this universe is based on the fact that an unplanned discovery of this universe became the source of attraction for researchers and scientists known as Big Bang Theory. This theory demonstrated that the world popped out as a wobbly and uneven micro-sized eager element which was called an atom (Malik et al., 2023). Little piece of this unstable component shaped the whole world and researchers and scientists are now more enthusiastic to discover some particles that are like to this little element such as micro particles (Zhang et al., 2022). The mystery of these little particles assures that these active particles even though smaller in size proved very effective in many industries. The mystery of nanoparticles has come to know with the existence of atoms (Farrokhi et al., 2024). By working more on these mysterious elements, researchers came to know about the existence of some particles that were shorter in size than atoms. These smallest elements were given the name of Nano-particles or nano-elements (Ahire et al., 2022). Richard P. Feyman was the first scientist who projected these microelements. These nanoparticles are the smallest and have many advantages in many emerging fields such as nano-biomedicine, nano-robots, and many other sub-fields (Moeinian et al., 2023). The major discovery of these elements led to the most important field of science which is known as Nano-biotechnology. Nanotechnology involves the combination of nanoparticles and technology to produce those items that are the hotspots for future perspective (Chehelgerdi et al., 2023). The demand of nano-biotechnology is very high concerning future. An atom usually comprises a size of 3 angstroms (3Å) while the size of a nanoparticle usually occurs as $10^{-9}$ of a material. In the early times, it was also considered that these nanoparticles were the spare part of atoms which has been separated by uneven distribution (Joudeh et al., 2022). The technology of nanoparticles has gained its importance to overcome so many future loads. The future is more depending on such types of technologies that pave the way easily for people (Martínez et al., 2022). The early diagnosis and detection of diseases, treatment of cancer, and pharmaceutical findings are now getting even better by using nano-biotechnology. On focusing more on the area of nanotechnology, the treatments are being improved and also many fields are related to being treated with these nanoparticles. Nano-technology and biotechnology are getting more in touch with each other by when there's come such conditions that are unable to be solved by using less efficient technologies (Suhag et al., 2023). The future demands are high enough to cope with the disease with other medical technologies because nanoparticles have gained importance in providing the way easy treatments. Their combined effects are usually increasing their trust on people to get more of their use (Pokrajac et al., 2021). There is a major improvement in techniques like PCR-based diagnosis, agriculture-based pathogen detection, sensors technology, imaging technology and drug discovery, high throughput discoveries and these techniques are now developing their designation as a Nano-based treatment. These Nano-based treatments prove very efficient in fulfilling future stresses (Dessale et al., 2022).

## 2. Application of Nano-Biotechnology

Using nanotechnology and biotechnology as a connected field doesn't only mean making the lives of people better but also increasing such technologies as in daily life use because such nanotechnologies are very efficient in giving the best results describe in Table 1 (Rajput et al., 2024). Now these nanomaterials have many significant applications in fields like manufacturing of different products, clearance of leftovers, wear and outfits, foodstuff, cosmetics, and even in today's life side by side shown in Figure 1 (Bayda et al., 2020). Numerous medicinal prospects are made possible by the special properties of ingredients at the nanoscale, including the capacity to modify and customize their physico-chemistry at the scale where bio-molecular interactions take place (Xia et al., 2022).

Table 1: Overview of Applications of Nano-Biotechnology

| Applications of Nano Biotechnology | | | |
|---|---|---|---|
| Areas of application | Examples | Advantages of applications | References |
| Nano-based drug delivery | Nanomedicine, Nanotubes, Nano capsules | Specific targeted treatment decreases the rate of mutations. | (Bayda et al., 2020) |
| Biosensors nanotechnology | Nano-bio detectors | For the diagnosis any disease at early stage | (Rajput et al., 2024) |
| Nanobased biofertilizers | Nanotubes, quantum technology, particles of gold and zinc | For detecting pathogens on crops, to protect crops from any kind of pesticides | (Suhag et al., 2023) |
| Nanobased environment cleanness | Nanobased filters, zinc oxide | Very suitable for removing pollutants from environment. | (Chehelgerdi et al., 2023) |
| Nanoctechnological robots | Graphite tubes | Widely used to support human health. | (Farrokhi et al., 2024) |

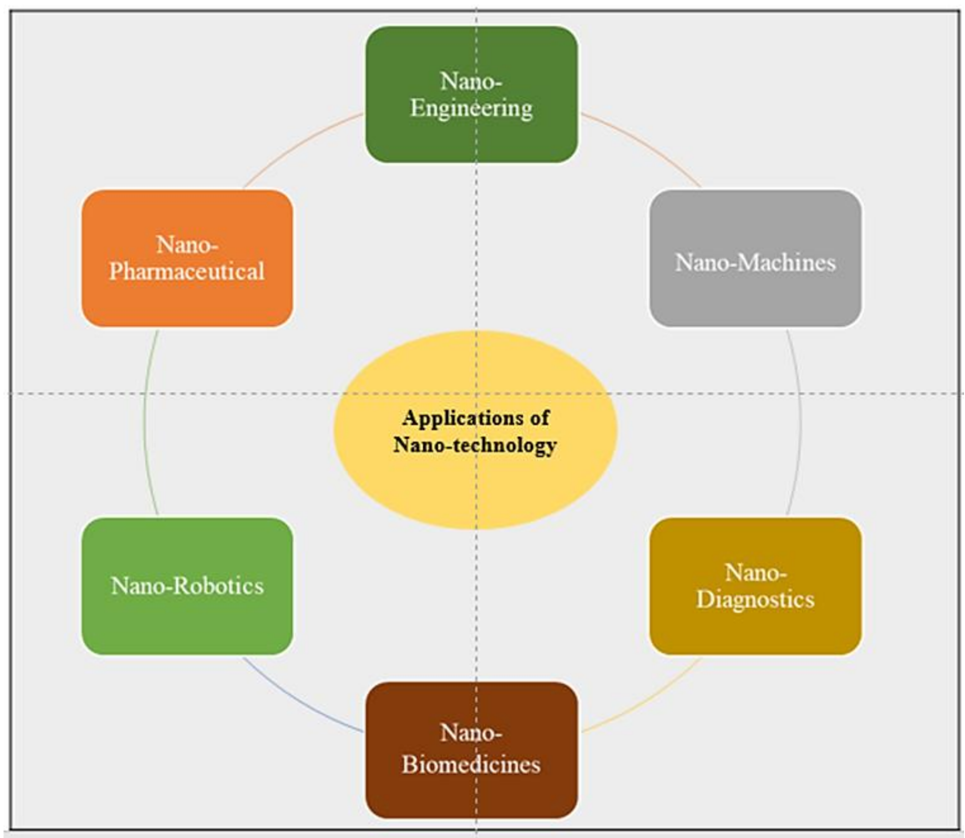


Fig. 1: Applications of Nano-biotechnology (Rederived from Biorender)

### 2.1. Carbon Nanomaterials

Carbon nanomaterials are the most emerging application of nanomaterials that gives a wide range of different techniques such as regeneration of tissues and cells, medicinal implants, delivery of certain drugs and vaccines, and also in some other important applications (Choudhary et al., 2024). Maximum size range of these carbon nanomaterials is from 1-100nm. Nano-biotechnology has been prominent as a most evolving field that has developed the treatment and analysis of illnesses and this is all happens because of the expansion and growth of carbon-nanomaterials approach with possible submissions for treatment of disease recovery and identification (Yan et al., 2023). Old CNMs were less efficient but the introduction of higher nano-scaled particles has become the source of more efficacy of outcomes. Carbon nanomaterials have a blend of possessions that are modified via production procedures to improve various characteristics like drug efficacy, optical commotion, biocompatibility and immunogenicity (Zhong et al., 2022). The material's high degree of control over many important properties gives it a benefit over metal-established biomaterials like titanium. There is an excellent example of titanium-based nanomaterials in treating the targeted drug site that proves very promising in giving higher results (Mamidi et al., 2020). Carbo nanomaterials has so many categories and these include carbon foam, fullerene or bucky-ball, nano-diamond, amorphous nano-carbon, single and multi-walled carbon nanotubes, quantum dots by graphene (Debnath et al., 2021). Carbon nanomaterials have many novel characters that may be applied to many vast biological fields. CNM has also gained an excellent approach to various anti-inflammatory and anti-cancerous stuffs (Mohanaraman et al., 2024). Further findings also conclude that carbon nanomaterials are more focused to being contaminated by various elements such as the production of metal ions (Behera et al., 2022). Overview of the Types of Carbon Nanomaterials shown in Figure 2.

### 2.1.1. Functionalization of Carbon-Nanomaterials

However, the effect of carbon nanomaterials increases the efficacy of delivery by decreasing the extended maintenance in the body (Behera et al., 2022). Some reports also propose that the involvement of carbon nanomaterials with reactive oxygen species may develop cancer cells by damaging the genetic material i.e. DNA and metabolism of lipids. It is also found that amplified amount of reactive oxygen species by graphene materials also bring changes in the metabolic movement of macrophages and destroys the many mitochondrial films which ultimately leads to programmed cell death (Varol et al., 2022). Carbon nanomaterials make their efficacy better usually by labeling various elements if they have some toxic effects such as they mark or tagging different proteins, DNA, amino acids, and drugs, and then function by decreasing the poisonousness of such elements (Peng et al., 2020).

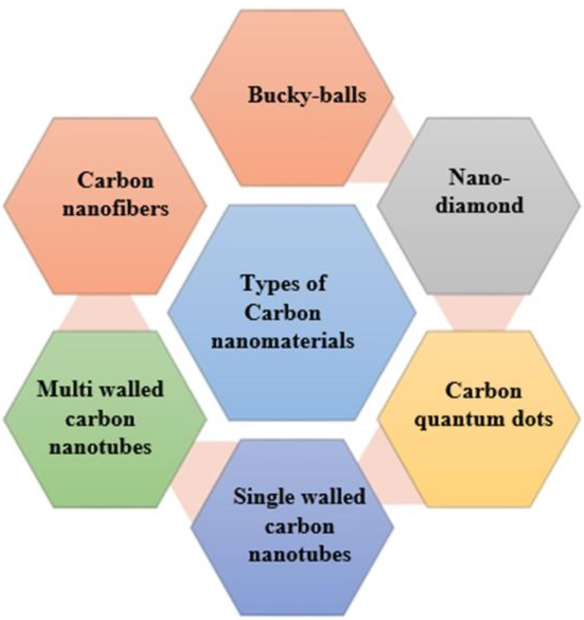


Fig. 2: Overview of the Types of Carbon Nanomaterials (Retrieved from Biorender)

### 2.2. Fullerenes

Buckyball is a type of carbon molecule that has many irreplaceable structural and electronic possessions and has novel applications in the field of medicine due to its outstanding abilities of being hydrophobic and configuration (Nurzynska et al., 2022). Particles of fullerene have gained its potential as an obstruction of HIV and also against many antibacterial and antiviral mechanisms (Mishra et al., 2021). One of the major advantages of using fullerenes is that these bucky-balls do not show any kind of toxicity, excluding the effects of its severity and non-severity. This is one of the benefits that these buckyballs proved effective in using favor of solubilization, physicochemical characteristics, and decreasing the behavior of toxicity shown in Figure 3 (Ghosh et al., 2023).

### 2.3. Nano-Diamonds

The discovery of the Nano-diamonds is similar to the structure of diamond-shaped material. Nano-diamonds mimic the structure of diamond particles to perform their work. In the structure of Diamonds, the involvement of a covalent bond with attached carbons to the single one makes it as well as it provides the hard nature to such diamonds (Pan et al., 2023). The structure of nano-diamonds is more similar in way to diamonds because they are also very strong, possess many unique characteristics, has a blend of mechanical strength, sparking nature, and novel thermos-conductive properties. Nano-diamonds, the most important form of carbon nanomaterials that occur in the size of usually 8nm and are covered with unique effective coatings of the group that prove helpful in decreasing the oversized connections. These nano-diamonds or even artificial nano-diamonds have low cost (Inal et al., 2023). Such suitable properties of these nano-diamonds with a medical point of view (Mohamed et al., 2024). Nano-diamonds have a very novel property such as they can carry substantial drug loads (Saldmann et al., 2020)

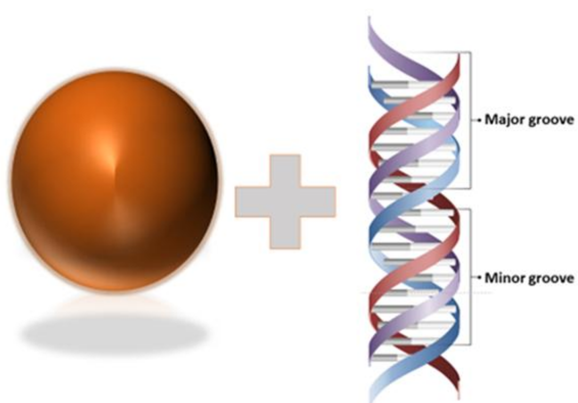


Fig. 3: An overview that represents the combination of buckyballs and biotechnology (Retrieved from Biorender)

### 2.4. Carbon Quantum Dots

Carbon quantum dots are widely used in the size range of less than 10nm and has extensive use in the areas of research because of their immense properties as they are nonhazardous and give fluorescence effects. Quantum dots are usually Nano-dots that has novel optics properties and because of their small sizes or dots, their activities are restricted (Desmond et al., 2021). Nano-scaled quantum dots get more similar to smaller carbon quanta. The characters of the Graphite carbon dots are also involved with these quanta (El-Shabasy et al., 2021). Carbon quantum dots have become the point of hotspots because of highest level of pressure and temperature ranges are used to make graphene, cellulose and other such stuff by using these carbon quantum dots. There fluorescence effects give 2 major phases; one of which is the radiation of band-gap fluorescence and the other is from the exterior i.e. surface phenomenon (Yang et al., 2023). Reactive oxygen species are also very stable with such CQD (Zou et al., 2020). Carbon quantum dots are more reliable to use in many fields. Carbon quantum dots has also important applications in the area of electric gadgets. The area of biomedical science is dependent on the use of carbon quantum dots to get considerable results because of unique fluorescence effects. They are widely used in the diagnosis and treatment of cancer, for precise delivery of medicines, solar power utilization, photo-driven reaction systems, and also for optical devices (Alaghmandfard et al., 2021). Combined Applications of Buckyballs, CNTs and Quantum Dots describe in Table 2.

Table 2: Combined Applications of Buckyballs, CNTs and Quantum Dots

| Combined Applications of Buckyballs, CNTs and Quantum Dots | | | | |
|---|---|---|---|---|
| CNTs | Carbon quantum dots | Fullerene | Relative advantage | References |
| Tissue Regeneration, Targeted delivery | Cancer Imaging | On site drug equilibrium | Combined effect in different therapies. | (El-Shabasy et al., 2021) |
| Batteries | Solar energy efficacy | Storage of certain gases potential | Mixed effects on energy conservation | (Joudeh et al., 2022) |
| Pollutants Identification | To measure pathogens in water | To determine the level of contamination | Integration to find pollution level and toxicity. | (Pan et al., 2023). |

### 2.5. Carbon Nanotubes

The other name for carbon nanotubes is famous bucky-tubes that usually have a hollow or cylindrical appearance made with nano-carbon related particles. Carbon-nanotubes are similar to the structure of simple tubes but these tubes are long and fine with attached carbon molecules in them (Norizan et al., 2020). These hollow carbons are blended upon the tubes and provide unique features by treating many diseases. Double-walled nano-based carbon tubes usually involve two graphene tubes in their production while multi-walled nanotubes involve many cylinder-shaped explosives of graphene sheets. In the areas of research, the double-walled carbon nanotubes are widely used because of their precise monitoring to detect the signals in many electric or medical surroundings (Duoc et al., 2020). Many other phenomena which are known as laser-induced material removal, pressurized carbon reaction, and vapor phase deposition method or vapor deposition by chemical method have been used for the production of such nanotubes (Nikolaev et al., 2023). Among all these methods, chemical vapor deposition has gained much potential because of its positive attitude towards nano-based carbon tubes. Those nanotubes that come to existence by using this method provide many aids by possessing high enactment of length and augmenting morphological properties (Fatehbasharzad et al., 2023). These nano scale carbon tubes are widely utilized in the field of medicine because of their highly tuneful traits. Many surgical tools have been designed using carbon nanotubes (Aoki et al., 2020).

### 2.6. Carbon Nanofibers

Carbon nanofibers come with a stable class and have confident conductive nature. Their physicochemical properties have a vast potential in medicine as they have an easy way to fields of pharmaceuticals, mechanism, and action of drug and their delivery, transfer of different DNA segments or genes to other living beings, for investigation of bio-sensors as well as in many other industries (Omoriyekomwan et al., 2021). Carbon nanofibers have been quickly evolving because of novel thermal, optical and structural properties. Other than that, carbon nanofibers offer a huge dimension for a surface era that makes them bendable for fulfilling the demands (Abdo et al., 2021). CNTs are also widely used in the textile factory and they are so cheap when contrasted with carbon nanotubes. Carbon nanofibers are produced through gas-vapor phase deposition method and point departure electrospinning. One of the biggest examples of carbon nanofibers involves the production of bio-sensors. The functional activity of CNF makes them unique part to dealing with higher demands (Gaur et al., 2021). Developing Level of Nanotechnology for Nanotubes and Nanofibers describe in Table 3.

Table 3: Developing Level of Nanotechnology for Nanotubes and Nanofibers

| Developing phases of Nanotechnology for Nanotubes and Nanofibers | | | |
|---|---|---|---|
| Phases | Nanotubes | Nanofibers | References |
| Concept stage | Carbon and graphite nanotubes | Drug transport across the whole body | (Gaur et al., 2021). |
| Experimental stage | Stimulus related to carbon tubes i.e. devices | Regeneration of tissue and medical scaffolds. | (Sharifianjazi et al., 2021) |

## 3. Drug Delivery Systems of Nanomaterials

The world is facing so many problems due to increased amount of cancer; a lot of lives have been lost. To combat this problem, nanotechnology has proved very beneficial to give a soothing effect throughout cancer treatment. Delivery of drugs to the targeted location has become possible by using nanomaterials shown in Figure 4 (Dutta et al., 2021). One of the important components called as magnetic nanomaterials when combined with some other materials such as an introduction of RNA or some chemo-therapeutic antidote or drugs give auspicious effect to treat cancer and minimize the side effects of chemotherapies (Pusta et al., 2023). Drug delivery mechanism is important for humans as well as for animals to treat different diseases and there are different routes to transfer the drug like pulmonary or nasal routes. Graphene or carbon-based nanoparticles are also widely being used (Bhardwaj et al., 2023). Damage to the skin and assembly of wounds sometimes seriously effect a patient’s life. To normalize the situation, nano-based materials show excellent effects towards healing of injuries. Nanoscale therapy represents as a prominent tool in such regard (Liu et al., 2023). Other than all, there is another eye-catching approach related to these nanoparticles involve hollow structure nano-based materials that corroborates very promising towards the areas of medical grounds. The function of these nanomaterials combined with a cavity and shell-like structure that give great surface era, shows the lowest density medium, and also enlarges the mass transmission. Such characteristics give leverage to activities like the transmission of drugs, providing outstanding dealings, and transportation of diverse elements (Li et al., 2023).

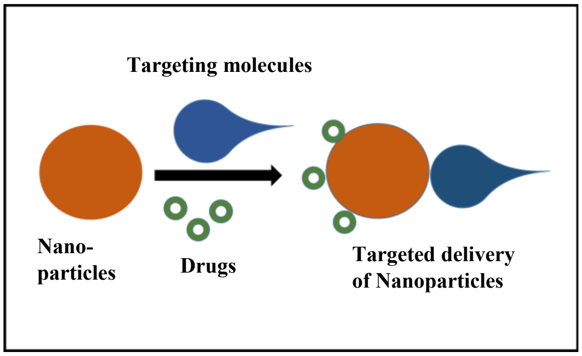


Fig. 4: Target delivery of Drugs Nanoparticles (Retrieved from Biorender)

4. Tissue Engineering

Nanoscale materials signify the most progressive technique to dealing with those patients who have suffered from the disaster of organ failure. One of the major applications of nanotechnology in this regard is the production of engineered tissues that has provided the solution to such loss (Zheng et al., 2021). A protruding type involves the polymeric bio-materials that are highly used because of their unique properties, malleable structure-activity, flexible nature, functional activity, solid power-driven asset, and appropriate living atmosphere. Nanomaterials also provide a high spot for making the tissue engineering activity better. Therefore, the improvement of biologically active compounds and porcelains has favored the use of tissue engineering (Khan et al., 2023). Tissue engineering technique specifically necessitates the usage of a permeable framework, which assists in the 3-dimension pattern or template for preliminary cellular connection and consequent muscle development mutually within the lab and outside the lab. Production of many organs such as artificial kidneys, liver, heart and the production of human body parts were made possible when tissue engineering techniques were more intact with the help of biotechnology (Halim et al., 2021). The combined effect of these nano-based particles on the making of tissue engineering helps more productivity in the medical field. Scaffolds are the primary source of obligatory provision for cellular activity to ascribe, produce and preserve their discriminated purpose. People are more reliable in using nano-scaled scaffolds because their efficacy is far better than simpler one. Nano-scaled scaffolds show promising effects in the treatment of many health-related issues (Chimerad et al., 2023).

5. Biosensors

Biosensors are also one of the most significant types of nanotechnology that usually sense the biological phenomena of materials. Biosensors are exactly similar to simple sensors. As simple sensors detect the sense of being sensitive and toxicity to certain conditions, biosensors are alike to these but these include some living forms that sense (Nagraik et al., 2021). Biosensors has a great use in so many industries like in medical, agriculture, the environment and even in food industry described in Table 4. With a medical point of view, to know the amount of being uncharacteristic happening or any other kind of change in the body, it measures the signals by using nanoscale technology (Karnwal et al., 2024). By conclusion the introduction of biosensor as it a device that includes transducer that generate the warmer, electrical or ocular indicator. The use of carbon nanomaterials played an important role in improving the methodical presentation because of the upsurge in an electro-chemically energetic shallow zone by utilizing fluorescent activity as well as in the production of biosensors especially electro-chemical and ocular biosensors (Ramesh et al., 2022). As cancer is one of the major causes of death in today's world so nano-scale biosensors prove to be an outstanding tool for cure cancer by giving early detection of cancerous cells in a patient so on time the patient's therapy can be started. Biosensors usually act as bio-markers and a combination of different nanoscale materials like CNTs, CNF, and Carbon Quantum Dots and more prominent graphene is being used to detect the cancer in lungs, breasts and even in the colon (Sharifianjazi et al., 2021). Other than cancer, HIV is also a great concern which ultimately leads to AIDS. A major drawback of HIV testing kits is that these kits are not being able to detect early infection of the virus which ultimately increases the exposure of diseases. Those HIV kits are built by using old methods. To combat this alarming situation, nano-based biosensors provide great easiness in such regards. HIV based nano-based kits show great suitability towards the treatment of HIV. These specific biomarkers attach to the specific location and produce a fluoresces effect and detection of virus molecules becomes possible on the very initial phases. The fluorescence effect that produced after detection saves a lot of time of researchers for diagnose the certain conditions (Farzin et al., 2020).

Table 4: Availability of Biosensors in different forms

| Different forms of biosensors with their examples | | |
|---|---|---|
| Type | Example | References |
| Diagnostic Biosensors | Pathogen detection, Pollutants detection | (Nagraik et al., 2021) |
| Magnetic Biosensors | Biomolecules identification | (Ramesh et al., 2022) |
| Updraft Biosensors | Temperature measurement | (Farzin et al., 2020) |

Ethical Concerns Related to Nano-based Biotechnology Materials

It is not a matter of fields but the fact about technologies, and every technology have its pros and cons and even ethical trepidations. As nano-biotechnology has played a significant role in providing the easiness to the lives of people their ethical concerns are also with-it side by side (Yousaf et al., 2024). cancer detection at the start of its spreading, the mutations diagnosis, disease recognization and targeted drug delivery methods have brought about a very calming effect by using nano-carbon tubes, nanofibers, bucky-balls and many more (Mohi-ud-din et al., 2020). Different nanotechnologies have different concerns but the Ethical concerns of these nanomaterials are also found along with its advantages. A major ethical concern in medicine is that sometimes those nanoparticles that are used in the treatment of diseases may gather in some parts of body or in organs that lead to damage to those parts by introducing toxicity to them (Arnold et al., 2022). Labeling of nano-based particles products is important because people become well aware of such products and use them according to the label. But there is also a concern that some companies provide risks by giving misinformation on providing miss labeling (Ukochovwera et al., 2023). There is still lacking of public acceptance about these nano-scaled particles. Some crops are also having nano-scaled labeling but people feel fear to talk about these labeled crops. Toxicity of such nano-elements bring very undesirable effect on health. There should be an informed consent that provides before treatment as approval for dealing with disease. Biosensors-based nano-techniques that used those sensors to detect the privacy of people and then misuse it, brings up a major ethical concern (Grunwald et al., 2020).

Conclusion

To overcome the challenging issues of today's world in different fields, especially in medical lines, Nano-based particles, and biotechnology together make a prominent field which is known famously as nano-biotechnology as one of the protuberant fields. Nano-biotechnology has been developed as one of the major fields of today's times and provides many benefits by giving with it outclasses advantages in the field whether it is related to medicine or agriculture, textile or food. The demand of nanoparticles is being increased day by day as different types of nano-based particles are effective in different fields for performing different valuable tasks. Near in the future, there will be more demands of these little particles to make the lives of people easier. With time, these nano-based techniques are getting better and people are usually more relay on these nano-based technologies.

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